

ASYMMETRY IN CHARMED PARTICLES PRODUCTION IN Σ^- BEAM

A.K. Likhoded¹ and S.R. Slabospitsky
State Research Center
Institute for High Energy Physics,
Protvino, Moscow Region 142284,
RUSSIA

Abstract

We present the calculation of the inclusive x_F -distributions of charmed hadrons, produced in high-energy Σ^- -beam. The calculation is based on the modified mechanism of charmed quarks fragmentation as well as on the mechanism of c -quark recombination with the valence quarks from initial hadrons. We predict the additional asymmetry in the production of charmed hadrons due to the different distributions of the valence s and d quarks in Σ^- -beam.

¹E-mail: LIKHODED@mx.ihep.su,

Introduction

In the hadronic production of particles with open charm an interesting situation, connected with the interaction of charmed quarks with the hadronic remnant, takes place (see [1, 2, 3] and references therein).

Let us remind that such a problem does not arise in the case of e^+e^- annihilation, where a heavy quark is hadronized due to its own radiation and all the description is reduced to the fragmentation function:

$$\frac{1}{\sigma_{c\bar{c}}} \frac{d\sigma}{dz} = D(z, Q^2) \quad (1)$$

here z is the part of the c -quark momentum, taken by charmed hadron and Q^2 is the square of total energy in the e^+e^- annihilation.

It is well known that a simple transition of factorization approach in the form of (1) to the charmed particle production in hadronic interaction leads to the valuable deviation from experimental data. Indeed, there is a substantial difference in the yield of different charmed hadrons in the fragmentation region ($|x| \rightarrow 1$, $x \equiv 2p_H/\sqrt{s}$) of initial hadrons.

This charmed particle yields asymmetry A (or “**leading particle effect**”) is defined as follows:

$$A = \frac{\frac{d\sigma}{dx}(\text{leading}) - \frac{d\sigma}{dx}(\text{nonleading})}{\frac{d\sigma}{dx}(\text{leading}) + \frac{d\sigma}{dx}(\text{nonleading})}. \quad (2)$$

Here symbol ‘leading’ or ‘non-leading’ refers to charmed hadron with or without light quarks identical to valence quarks from initial hadrons. For example, in $\pi^- (\bar{\mathbf{u}}\mathbf{d})$ -beam the mesons $D^0(c\bar{\mathbf{u}})$ and $D^-(c\bar{\mathbf{d}})$ are leading particles, while $\bar{D}^0(\bar{c}\mathbf{u})$ and $D^+(c\mathbf{d})$ should be considered as non-leading ones.

There are many theoretical articles devoted to description of a such phenomenon [4]. In our previous [5, 6] publications we have taken into account the interaction of c -quarks with quarks of the initial hadrons and obtained a good agreement with the data in the spectra description at large x and the x -asymmetry dependence in $\pi^- N$ and $\Sigma^- N$ -interactions.

The recent data on the charm production in the Σ^- -beams [2, 3] are of special interest due to the fact that the beam hadron (here Σ) has s -quark and as consequence the distribution functions of the valence quarks in the Σ^- -baryon differ from that of proton [7]. It has to lead to the set of

observable effects and, in particular, to the another asymmetry in the yield of the charmed hadrons that in the case of proton-proton collisions.

Preliminary data presented by the SELEX Collaboration [3] on the charm yield in the Σ^-p and π^-p collisions show however some disagreement with other experiments [2] and general theoretical assumptions, in particular, in the expected charmed particle and anti-particle yields in the central region.

In this article we consider very briefly this problem from general theoretical point of view (Section 1). In the Section 2 we give a short description of the fragmentation mechanism. Our approach for calculation of x -distributions of charmed-particle production in recombination mechanism is given in the Section 3. We present the predictions for differential distributions of charmed hadrons produced in Σ^-N -interactions in the Section 4. A short summary of the results is given in the Conclusion.

1 Asymptotic behavior in the central region

Before discussing in detail of the spectra behavior and the charge asymmetry in the hadron yield let us consider general behavior of charmed particle spectra.

According to the generalized optical theorem [8] an inclusive spectrum is connected with the discontinuity of the sixth particle amplitude by the following relation (see Fig. 1.):

$$E \frac{d^3\sigma}{d^3p} = \frac{1}{s} \text{disc} M_{3 \rightarrow 3}, \quad (3)$$

where s is the total energy squared.

Let us introduce two invariants (see Fig.1)

$$s_1 = (p_a + p_c)^2, \quad s_2 = (p_b + p_c)^2.$$

At the high energies the asymptotic behavior of the $M_{3 \rightarrow 3}$ amplitude as a function of these invariants $s_{1,2}$ is determined by leading Regge trajectories, namely, the Pomeron (\mathcal{P}) and secondary trajectories (\mathcal{R}_i), related to ρ , ω , f , A_2 mesons. In so doing, the \mathcal{PP} , \mathcal{RP} , and \mathcal{RR} contributions become important.

In the central region ($x \sim 0$), where the kinematic invariants s_1 and s_2 are large, one has

$$s_1 \approx \sqrt{s} m_\perp e^{-y}, \quad s_2 \approx \sqrt{s} m_\perp e^y, \quad (4)$$

where y is the rapidity and $m_\perp = \sqrt{m^2 + p_\perp^2}$.

Double Regge representation is a good approximation for the $M_{3 \rightarrow 3}$ amplitude (see Fig.1) in this kinematic region. So, one has

$$E \frac{d^3\sigma}{d^3p} \approx \frac{1}{s} \sum_{i,j} \tilde{f}_{ij} s_1^{\alpha_i} s_2^{\alpha_j} \quad (5)$$

where α_i and α_j are the intercepts of the leading Regge-trajectories [8, 11]. For Pomeron trajectory one has $\alpha_P \approx 1$, while the f, ρ, ω, A_2 trajectories have the intercept $\alpha_R \approx 1/2$.

The $\tilde{f}_{ij}(m_\perp)$ are unknown functions of m_\perp , but it seems that these functions are universal and do not depend on the type of produced particles [8, 9]. These functions can be determined by fitting to experimental data. All the dependence on quantum numbers of initial and final particles is determined by the coupling constants of the secondary Reggeons \mathcal{R} , included to the definition of the $\tilde{f}_{ij}(m_\perp)$ functions.

After substituting $s_{1,2}$ from (4) the expression (5) takes the form:

$$E \frac{d^3\sigma}{d^3p} = \tilde{f}_{\mathcal{P}\mathcal{P}}(m_\perp) - \sum_{i,j} \frac{\tilde{f}_{ij}(m_\perp)}{s^{1-\frac{\alpha_i+\alpha_j}{2}}} e^{(\alpha_j-\alpha_i)y} \quad (6)$$

This equation provides a good description of the transition to the asymptotic regime in the “central” region for all variety of the yields of π - and K -mesons [9].

For the D - and B -meson cases the expression (6) simplifies due to the fact that the contribution of the trajectories, connected with a charmed c -quark in D -meson ($J/\psi, \chi_c$ trajectories) or beauty b -quark in B -meson (Υ, χ_b trajectories), is strongly suppressed by the Zweig rule for the coupling with initial mesons or nucleons. Therefore, in the sum of Eq. (6) there are no contributions with two secondary Reggeons ($\mathcal{R}\mathcal{R}$ -contributions) in the upper and bottom “shoulder” of the diagram in Fig. 1. So, one gets more simple expression:

$$E \frac{d^3\sigma(D)}{d^3p} \approx \tilde{f}_{\mathcal{P}\mathcal{P}}(m_\perp) - \frac{1}{4\sqrt{s}} \{ \tilde{f}_{\mathcal{R}\mathcal{P}}(m_\perp) e^{y/2} + \tilde{f}_{\mathcal{P}\mathcal{R}}(m_\perp) e^{-y/2} \}. \quad (7)$$

Note, that the contribution of the first \mathcal{PP} -term in the equation (7) is the same for the particle and anti-particle and is proportional to the total cross-section of the interaction of initial hadrons. Thus, the normalized cross-section

$$\frac{1}{\sigma_{tot}^{hh}} E \frac{d^3\sigma(hh \rightarrow D X)}{d^3p}$$

at high energy limit has one universal limiting value independently on the type of colliding hadrons.

For the case of the D_s -meson production in the Σ or K -beams the leading intercept is related to ϕ -meson, $\alpha_j = \alpha_\phi \approx 0$ and there is no contribution from the third \mathcal{PR} -term in Eq. (7). The ϕ -trajectory can be connected with Σ -particle only, because there are no valence strange quarks in the proton. As a result, one has only two terms:

$$\frac{1}{\sigma_{tot}} E \frac{d^3\sigma(D_s)}{d^3p} \approx \tilde{f}_{\mathcal{PP}}(m_\perp) - \frac{1}{\sqrt{s}} \tilde{f}_{\mathcal{RP}}(m_\perp) e^y \quad (8)$$

The contribution of secondary trajectories determines the difference between the yields of the particle and anti-particle in the central region. For instance, for pp and $p\bar{p}$ -collisions one has

$$\Delta_{pp} \sim \frac{a}{s^{1/4}} ch \frac{y}{2}, \quad \Delta_{p\bar{p}} \sim \frac{b}{\sqrt{s}} sh \frac{y}{2},$$

where the a and b coefficients depend on both combinations of secondary Reggeon couplings and particle type of D - or B -meson.

In the most experiments on fixed target the point $y = 0$ ($x = 0$), as a rule, is out of reach due to the experiment conditions, and the measured spectrum starts from $x \sim 0.1$. With a simple substitution $y \simeq \ln(x \frac{\sqrt{s}}{m_\perp})$ for D -mesons the equation (7) takes the form

$$\frac{1}{\sigma_{tot}} E \frac{d^3\sigma(D)}{d^3p} \simeq \tilde{f}_{\mathcal{PP}}(m_\perp) - \{ \tilde{f}_{\mathcal{RP}}(m_\perp) \sqrt{m_\perp} \sqrt{x} + \tilde{f}_{\mathcal{PR}}(m_\perp) \frac{\sqrt{m_\perp}}{\sqrt{sx}} \} . \quad (9)$$

For D_s -meson production in the Σ or K beams one has:

$$\frac{1}{\sigma_{tot}} E \frac{d^3\sigma(D_s)}{d^3p} \simeq \tilde{f}_{\mathcal{PP}}(m_\perp) - \tilde{f}_{\mathcal{RP}}(m_\perp) m_\perp x \quad (10)$$

The asymmetry in the particle yield, which depends on the quantum numbers of initial hadrons and observed charmed particles, is determined by the second term in these expressions, which is different for the D and D_s cases. One can see that the transition to the asymptotics at fixed x is achieved much faster than in the regime of the fixed rapidity. It is seen also that the behavior in the vicinity of $x = 0$ is determined by the value of intercept of secondary trajectory connected with valence quark, common for the beam hadron and observed particle.

It is quite evident that the applicability region of the above expressions is severely restricted by the necessity to fulfill the condition of large values of the s_1 and s_2 invariants in the case of the Regge approximation. However, the general conclusions on the character of an asymptotic behavior of charmed particle spectra, which can be obtained from them, on the one hand, are quite definite, and, on the other hand, agree well with the parton model predictions.

We wish to stress once more, that from general theoretical consideration one should expect equal yields of the charmed particle and anti-particle in the central region ($x \approx 0$) when $s \rightarrow \infty$:

$$E \frac{d^2\sigma(D)}{d^3p} \Big|_{x \approx 0} \approx E \frac{d^2\sigma(\bar{D})}{d^3p} \Big|_{x \approx 0} \quad (11)$$

As we will show such behavior is agree also with parton model predictions.

2 Fragmentation mechanism

In our previous publications [5, 6] we developed the phenomenological model model, where the hadronization of charmed c -quark is described by the sum of two mechanisms, namely

$$\frac{d\sigma_H}{dx} = \frac{d\sigma_H^F}{dx} + \frac{d\sigma_D^R}{dx}, \quad (12)$$

where the first term corresponds to the charmed quark fragmentation, while the second term takes into account the charmed c -quark interaction with valence quarks from initial hadrons (**recombination**).

In the fragmentation mechanism the inclusive cross section for the charmed hadrons (D -mesons) production has the form as follows:

$$E_H \frac{d^3\sigma^F}{d^3p_H} = \int E_c \frac{d^3\sigma(h_1 h_2 \rightarrow cX)}{d^3p_c} D(z) \delta(\vec{p}_H - z\vec{p}_c) d^3p_c. \quad (13)$$

where $z = |\vec{p}_H|/|\vec{p}_c|$ is the fraction of the c -quark momentum carried away by the charmed hadron H .

The parameterization of the fragmentation function $D(z)$ (for example, in the form from [12] or [13]) can be found by fitting to the data from reaction $e^+e^- \rightarrow D(c\bar{q}) X$. However, in hadronic collisions the situation is more complicated. Indeed, the use of the fragmentation function is justified at asymptotically large values of the invariant mass of $c\bar{c}$ pair or high p_T . However, in hadronic production of the charmed particles the main contribution into inclusive charm production cross section results from c -quarks with low values of the invariant mass of $c\bar{c}$ pair ($M_{c\bar{c}} \geq 2m_c$) [10]. These quarks dominate in the region small x . At the same time there is large amount of partons from initial hadrons in the same (central) region of x . Therefore, the c -quark in combination with one of such a parton can easily to produce a charmed hadron. Such a process occurs practically without any loss of c -quark momentum (i.e. $\vec{p}_H \approx \vec{p}_c$). Therefore, in the small x region one should expect the coincidence of the spectra of charmed hadrons and c -quarks. Whereas at high x region one may use the conventional fragmentation mechanism.

Following these arguments we have proposed the modified form of the fragmentation function [6]

$$D^{MF}(z, M_{c\bar{c}}) \sim z^{-\alpha(M_{c\bar{c}})}(1-z), \quad (14)$$

with two additional conditions on $\alpha(M_{c\bar{c}})$:

$$\begin{aligned} \alpha(M_{c\bar{c}}) &\rightarrow -\infty & D(z) &\rightarrow \delta(1-z) & \text{at } M_{c\bar{c}} &\rightarrow 2m_c, \\ \alpha(M_{c\bar{c}}) &\rightarrow \alpha_c \approx -2.2 & D(z) &\rightarrow z^{-\alpha_c}(1-z) & \text{at } M_{c\bar{c}} &\approx M_0. \end{aligned} \quad (15)$$

The explicit form of $\alpha(M_{c\bar{c}})$ equal

$$\alpha(M_{c\bar{c}}) = \frac{1 - 3\mu(M_{c\bar{c}})}{1 - \mu(M_{c\bar{c}})},$$

where

$$\mu(M_{c\bar{c}}) = \left(\frac{\ln(\frac{M_{c\bar{c}}}{2m_c} q_0)}{\ln q_0} \right)^{0.464}, \quad q_0 \approx 0.12$$

Note, that the usage of the fragmentation function assumes the absence of the interaction of the produced heavy c -quark with the remnants of the initial hadrons. Therefore, it should be no difference between the spectra of charmed and anti-charmed hadrons. Moreover, any modification of the fragmentation mechanism can not reproduce the production asymmetry (the leading particle effect).

3 Recombination mechanism

The fragmentation mechanism can be apply for the production of the $c\bar{c}$ pair in the color-singlet state or for high p_T production of the open charm. On the other hand, for the case of the hadronic production of color $c\bar{c}$ pair with small p_T one should takes into account the possibility of charmed c and \bar{c} quarks interaction with the initial hadron remnants. Therefore, due to the different valence quarks in the initial hadrons one may expect the different inclusive spectra of the final charmed hadrons.

In the parton model framework, a heavy c -quark should interact with a high probability with its nearest neighbor in the rapidity space able to form a color-singlet state with it. In some cases, the heavy anti-quark (quark) may find itself close (in rapidity space) to a valence light quark (diquark) from the initial hadron. This would result in the formation of a fast heavy meson (baryon) in the fragmentation region of the initial hadron.

We use the model [5, 6] to describe the production asymmetry for charmed hadrons. In this model the interaction of the charmed quarks with valence quarks from the initial hadrons describes with the help of the recombination function [5, 6]. The recombination of the valence q_V and \bar{c} quarks into D -meson is described by the function of $R_M(x_V, z; x)$:

$$R_M(x_q, z; x) = \frac{\Gamma(2 - \alpha_q - \alpha_c)}{\Gamma(1 - \alpha_c)\Gamma(1 - \alpha_q)} \xi_q^{(1-\alpha_q)} \xi_c^{(1-\alpha_c)} \delta(1 - \xi_q - \xi_c), \quad (16)$$

where $\xi_q = x_q/x$ and $\xi_c = z/x$, while x_q , z , and x are the fractions of the initial-hadron c.m. momentum that are carried away by the valence q -quark, charmed c -quark, and the $D(\bar{c}q)$ -meson, respectively. The corresponding recombination of three quarks into baryon can be described by means of the

similar recombination function:

$$R_B(x_1, x_2, z; x) = \frac{\Gamma(3 - \alpha_1 - \alpha_2 - \alpha_c)}{\Gamma(1 - \alpha_1)\Gamma(1 - \alpha_2)\Gamma(1 - \alpha_c)} \times \xi_1^{(1-\alpha_1)} \xi_2^{(1-\alpha_2)} \xi_c^{(1-\alpha_c)} \delta(1 - \xi_1 - \xi_2 - \xi_c). \quad (17)$$

These functions take into account the momentum conservation and the proximity of partons in the rapidity space. Actually, the recombination function is the modulus squared of the heavy meson (baryon) wave function in momentum space, being considered in the infinite momentum frame in the valence quark approximation.

With the help of the function $R(x_V, z; x)$ describing the recombination of the quarks q_V and \bar{c} into a meson, we represent the corresponding contribution to the inclusive spectrum of D meson as follows [5, 6]:

$$x^* \frac{d\sigma^R}{dx} = R_0 \int x_V z^* \frac{d^2\sigma}{dx_V dz} R(x_V, z; x) \frac{dx_V}{x_V} \frac{dz}{z}, \quad (18)$$

where $x^* = 2E/\sqrt{s}$ and $x = 2p_l/\sqrt{s}$ (here, E and p_l are the energy and longitudinal momentum of the D -meson in the c.m.s. of the initial hadrons); x_V and z are the momentum fractions carried away by the valence quark and heavy anti-quark, respectively, and $x_V z^* \frac{d^2\sigma}{dx_V dz}$ is the double-differential cross section for the simultaneous production of the quarks q_V and \bar{c} in a hadronic collision. The equation describing the production of charmed baryon has an analogous form.

The parameter R_0 is the constant term of the model, that determines the relative contribution of recombination. We fit the data on charmed hadrons production in $\pi^- N$ collisions and found that $R_0 \approx 0.8$ [6].

Note, that using of the recombination with the valence quarks provides a well description of the leading particle effect. At the same time its contribution in the total inclusive cross section production of the charmed particles is sufficiently small ($\sim 10\%$). This mechanism dominates in the high x region.

Note, that this model provides more or less successful description of the charmed D -meson production in $\pi^- N$ -interactions (see Fig. 2, 3 and [6] for details).

4 Charm production in Σ -beam

In this section we consider the charmed hadron production in high-energy beam of Σ^- -hyperon. First of all we expect the various behavior of the distributions of the valence d - and s -quarks. Indeed, as a first approximation, the distribution of valence quark in the baryon $B(q_1 q_2 q_3)$ can be presented as follows [5, 6]:

$$V_{q_1}^B(x) \propto x^{-\alpha_1} (1-x)^{\gamma_b - \alpha_2 - \alpha_3}, \quad (19)$$

where α_i is the intercept of the leading Regge-trajectory for q_i -quark, while $\gamma_B \simeq 4$. Note, that due to violation flavor $SU(N)$ -symmetry, we have different intercepts for $d(u)$ - and s -quarks [11, 12]:

$$\alpha_u = \alpha_d = \frac{1}{2}, \quad \alpha_s \approx 0, \quad \alpha_c \approx -2.2. \quad (20)$$

As a result, the x -dependence of the valence d and s -quark in the $\Sigma^-(sdd)$ -hyperon has the form as follows [7]:

$$V_d^\Sigma \sim \frac{1}{\sqrt{x}} (1-x)^{3.5}, \quad V_s^\Sigma \sim (1-x)^3 \quad (21)$$

It is seen from the (21) that the valence s -quark in the Σ^- -hyperon has harder x -distribution than that for d -quark. Note, that gluon distribution in Σ -hyperon has the same form as in usual nucleon. As a result, we expect more harder x -dependence of s -quark distribution in Σ -hyperon than u -quark distribution in nucleon. Thus, one may expect slightly harder spectrum of D_s -mesons, produced in Σ -beam, then spectrum of D^0 -mesons, produced in *nucleon*-beam. On the other hand, d -quark in Σ -hyperon should be slightly softer then that in nucleon. As a result we should observe the different x_F -dependence of spectra of charmed hadrons with d - or s -quarks, namely, $D^-(\bar{c}d)$ and $D_s^-(\bar{c}s)$, $\Xi_c^0(cds)$ and $\Sigma_c^-(cdd)$, etc.

We use LO formulas for calculations of the cross sections for quark-antiquark and gluon-gluon annihilation into $c\bar{c}$ -pair. We set $m_c = 1.25$ GeV and the value of strong coupling constant equals 0.3. Then for the cross section value of $\Sigma^- p$ interaction at $P_{LAB} = 600$ GeV one has:

$$\sigma(\Sigma^- p \rightarrow c\bar{c}X) \simeq 8 \mu b \quad (22)$$

In our calculations we do not pretend to reproduce the absolute value of this cross section (see [10], for detail consideration of this problem). We

concentrate on the description of x_F -distribution of charmed mesons and baryons.

Recently, we have done the calculations of asymmetry of x -spectra for D , D_s and Λ_c hadrons produced in Σ^- beam with the energy of 340 GeV. The WA89 Collaboration have compared these predictions with their experimental data [2]. This comparison is presented in Fig.4. As is seen from the picture the asymmetry in D -meson production in Σ -beam is different from that in π^- -beam and there is more pronounced asymmetry for D_s -meson production.

Below we present the predictions for charmed hadrons production in Σ^- -beam at 600 GeV energy. The corresponding distributions (integrated over p_T) are presented in Fig.5. We may see from these figures, that the considered charmed quark interaction in the final state (recombination) leads, indeed, to noticeable differences in x_F -spectra. These differences can be explicitly seen in Fig.6, where we present the corresponding asymmetry A (see (2) for definition). The most non-trivial prediction of the proposed model is presented in two lower plots in Fig.6, where we present the ratio of the inclusive spectra of $D_s^{*-}(\bar{c}s)$ and $D^{*-}(\bar{c}d)$ mesons as well as Ξ_c^0 and Σ_c^0 baryons. Indeed, due to the difference of the valence d and s quarks in the Σ^- -beam (see (21)) we expect the additional asymmetry in the leading charmed particles production.

5 CONCLUSION

In the present article we wish to stress once more, that the source of the observed asymmetry in charmed hadron production is the interaction of produced charmed quarks with valence quarks from initial hadrons. Note, the model under consideration provides also the additional method to measure the valence quark distribution functions of Σ -baryons.

ACKNOWLEDGMENTS

The authors thank E. Chudakov, A. Kushnirenko, O. Piskunova, and J.S. Russ for the fruitful discussions.

This work was supported in part by Russian Foundation for Basic Re-

search, projects no. 99-02-16558.

P.S. When this article was finished we received the article [14] with the recent results of E791 Collaboration. They present the inclusive x and p_T distributions of charmed hadrons, produced in π^- -beam. In particular, they observed a noticeable asymmetry in Λ_c^+ and $\overline{\Lambda}_c^-$ baryons production in the forward region (about 13%). Note, that our model can not explain this result. Due to the equal amounts of valence $\overline{\mathbf{u}}$ and \mathbf{d} quarks in the π^- -beam we expect an equal yields of the $\Lambda_c^+(cu\mathbf{d})$ and $\overline{\Lambda}_c^-(c\overline{\mathbf{u}}\mathbf{d})$ baryons in the π^- -beam. Moreover, the most theoretical models [4] predicts also zero asymmetry for these particle production.

References

- [1] J. C. Anjos [E791 Collaboration], hep-ex/9912039;
E. M. Aitala *et al.* [E791 Collaboration], Phys. Lett. **B411** (1997) 230 [hep-ex/9708040];
E. M. Aitala *et al.* [E791 Collaboration], Phys. Lett. **B371** (1996) 157;
M. I. Adamovich *et al.* [WA82 Collaboration], Phys. Lett. **B305** (1993) 402;
G. A. Alves *et al.* [E769 Collaboration], Phys. Rev. Lett. **77** (1996) 2388;
G. A. Alves *et al.* [E769 Collaboration], Phys. Rev. Lett. **72** (1994) 812.
- [2] M. I. Adamovich *et al.* [WA89 Collaboration], Eur. Phys. J. **C8** (1999) 593 [hep-ex/9803021].
- [3] M. Iori *et al.* [SELEX Collaboration], hep-ex/9910039;
M. Iori [SELEX Collaboration], Nucl. Phys. Proc. Suppl. **75B** (1999) 16;
F. G. Garcia and S. Y. Jun [SELEX Collaboration], hep-ex/9905003.
- [4] R. Vogt and S. J. Brodsky, Nucl. Phys. **B478** (1996) 311 [hep-ph/9512300];
T. Gutierrez and R. Vogt, Nucl. Phys. **B539** (1999) 189 [hep-ph/9808213];
J. C. Anjos, J. Magnin, F. R. Simao and J. Solano, hep-ph/9806396;
E. Cuautle, G. Herrera and J. Magnin, Eur. Phys. J. **C2** (1998) 473 [hep-ph/9711354];
G. Herrera and J. Magnin, Eur. Phys. J. **C2** (1998) 477 [hep-ph/9703385];
J. dos Anjos, G. Herrera, J. Magnin and F. R. Simao, Phys. Rev. **D56** (1997) 394 [hep-ph/9702256];
O. I. Piskounova, hep-ph/9904208;
T. Tashiro, H. Noda, K. Kinoshita and S. Nakariki, hep-ph/9810284.
G. H. Arakelian and S. S. Yeremian, hep-ph/9808325;
G. H. Arakelian, Phys. Atom. Nucl. **61** (1998) 1570 [hep-ph/9711276];
E. Norrbin and T. Sjostrand, hep-ph/0005110;
E. Norrbin and T. Sjostrand, Phys. Lett. **B442** (1998) 407 [hep-ph/9809266].

- [5] V. G. Kartvelishvili, A. K. Likhoded, and S. R. Slabospitsky, *Yad. Fiz.* **32** (1980) 236; *Yad. Fiz.* **33** (1981) 832;
A. K. Likhoded, S. R. Slabospitsky, and M. V. Suslov, *Yad. Fiz.* **38** (1983) 727.
- [6] A. K. Likhoded and S. R. Slabospitsky, *Phys. Atom. Nucl.* **60** (1997) 981; *Phys. Atom. Nucl.* **62** (1999) 693; hep-ph/0002202.
- [7] V. V. Kiselev, A. K. Likhoded and S. R. Slabospitsky, IFVE-86-45.
- [8] A. H. Mueller, *Phys. Rev.* **D2** (1970) 2963;
V. Kancheli, *JETP. Lett.* **11** (1970) 397.
- [9] M. N. Kobrinsky, A. K. Likhoded and A. N. Tolstenkov, *Sov. J. Nucl. Phys.* **20** (1975) 414;
P. V. Chliapnikov, A. K. Likhoded and A. N. Tolstenkov, *Yad. Fiz.* **26** (1977) 153.
- [10] Mangano M., Nason P., and Ridolfi G., *Nucl. Phys.* **B405** (1993) 507.
- [11] Collins, P.D.B., "*An Introduction to Regge Theory and High Energy Physics*", Cambridge: Cambridge University Press, 1977.
- [12] Kartvelishvili V.G., Likhoded A.K., and Petrov V.A., // *Phys. Lett.* **B78** (1978) 615.
- [13] Peterson C., Schlatter D., Schmitt I., and Zerwas, P., // *Phys. Rev.* **D27** (1983) 105.
- [14] E. M. Aitala *et al.* [E791 Collaboration], FERMILAB-Pub-00-025-E, hep-ex/0008029.

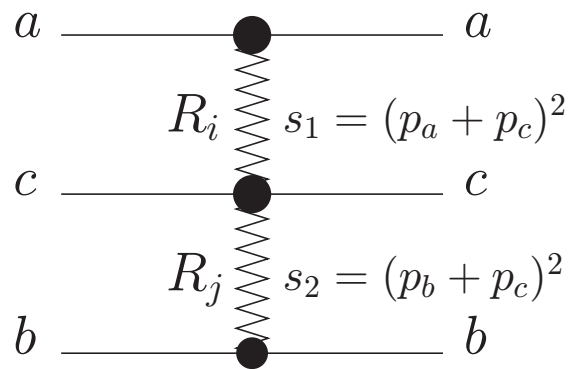


Figure 1: Six particle $M_{3 \rightarrow 3}$ amplitude.

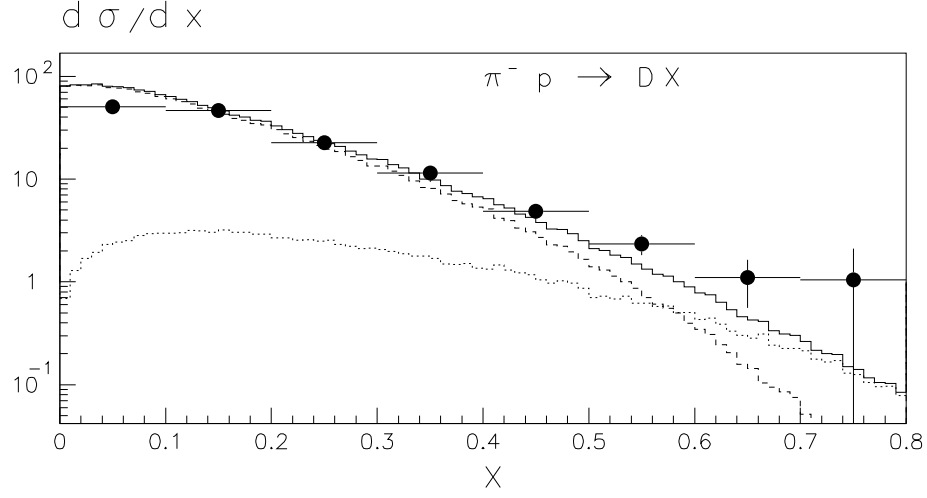


Figure 2: Differential distributions $\frac{d\sigma}{dx}$ for the energy of $E_\pi = 250$ GeV [1]. The dotted (dashed) histogram corresponds to the recombination (fragmentation) contribution. The solid histogram represents their sum. The cross sections are presented in μb (see [6] for details).

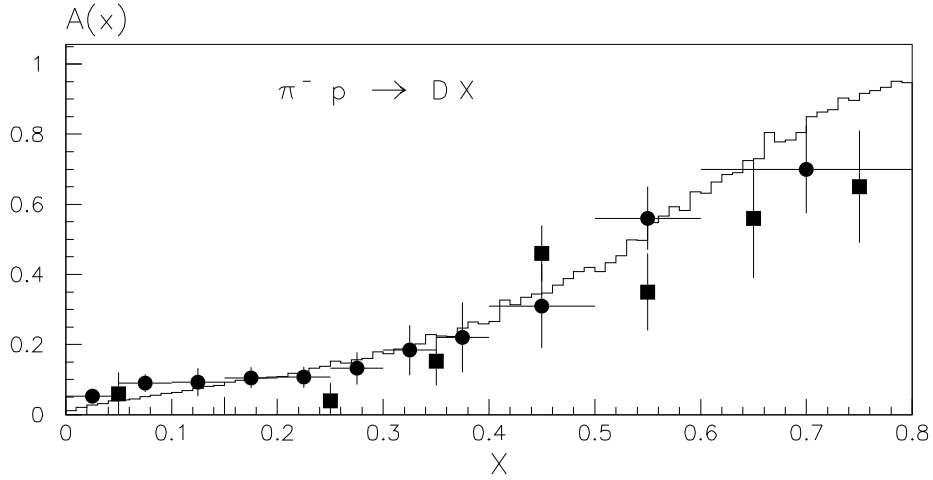


Figure 3: The description of the asymmetry $A(x)$ in $\pi^- p$ collisions (see [6] for details)

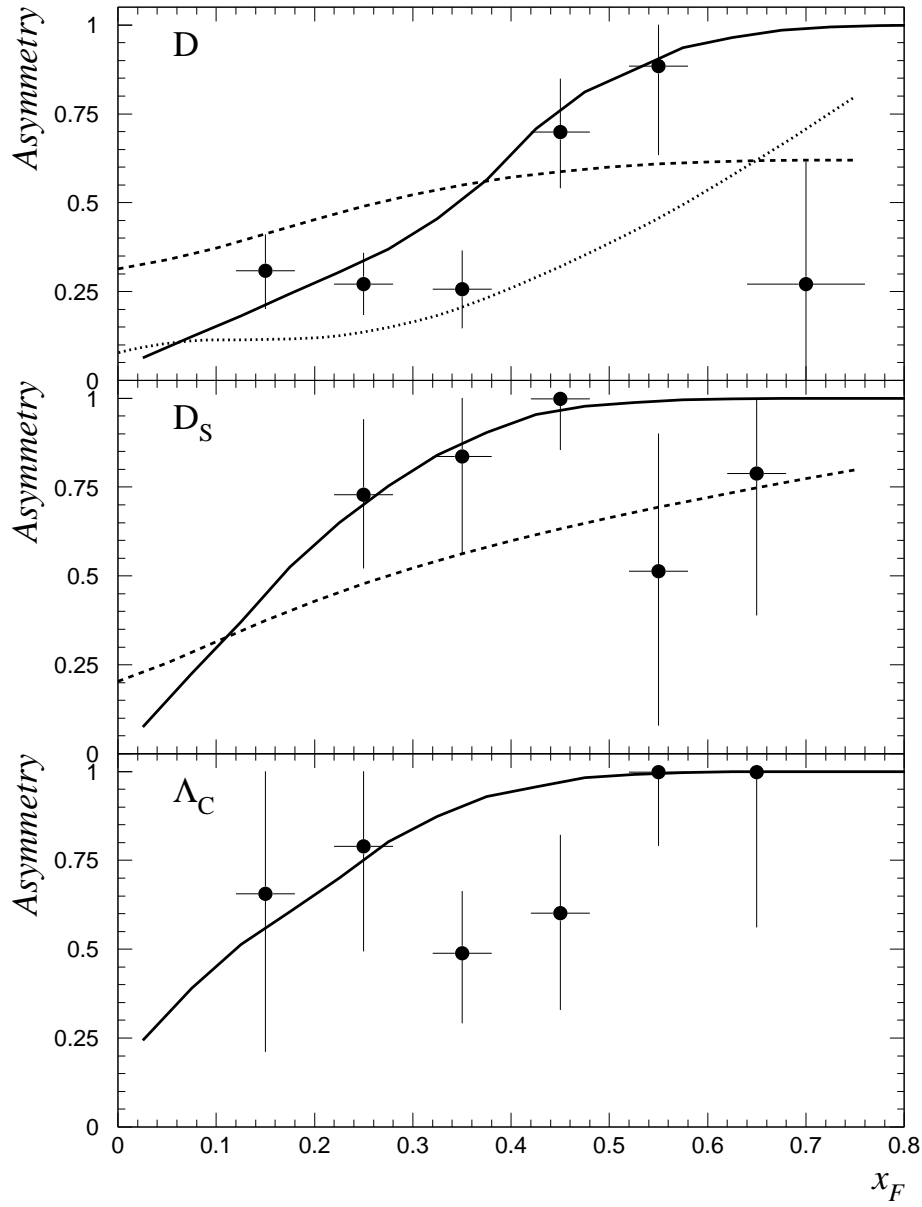


Figure 4: The asymmetry in the charmed hadrons produced in $\Sigma^- p$ interactions at $P_{LAB} = 340$ GeV [2].

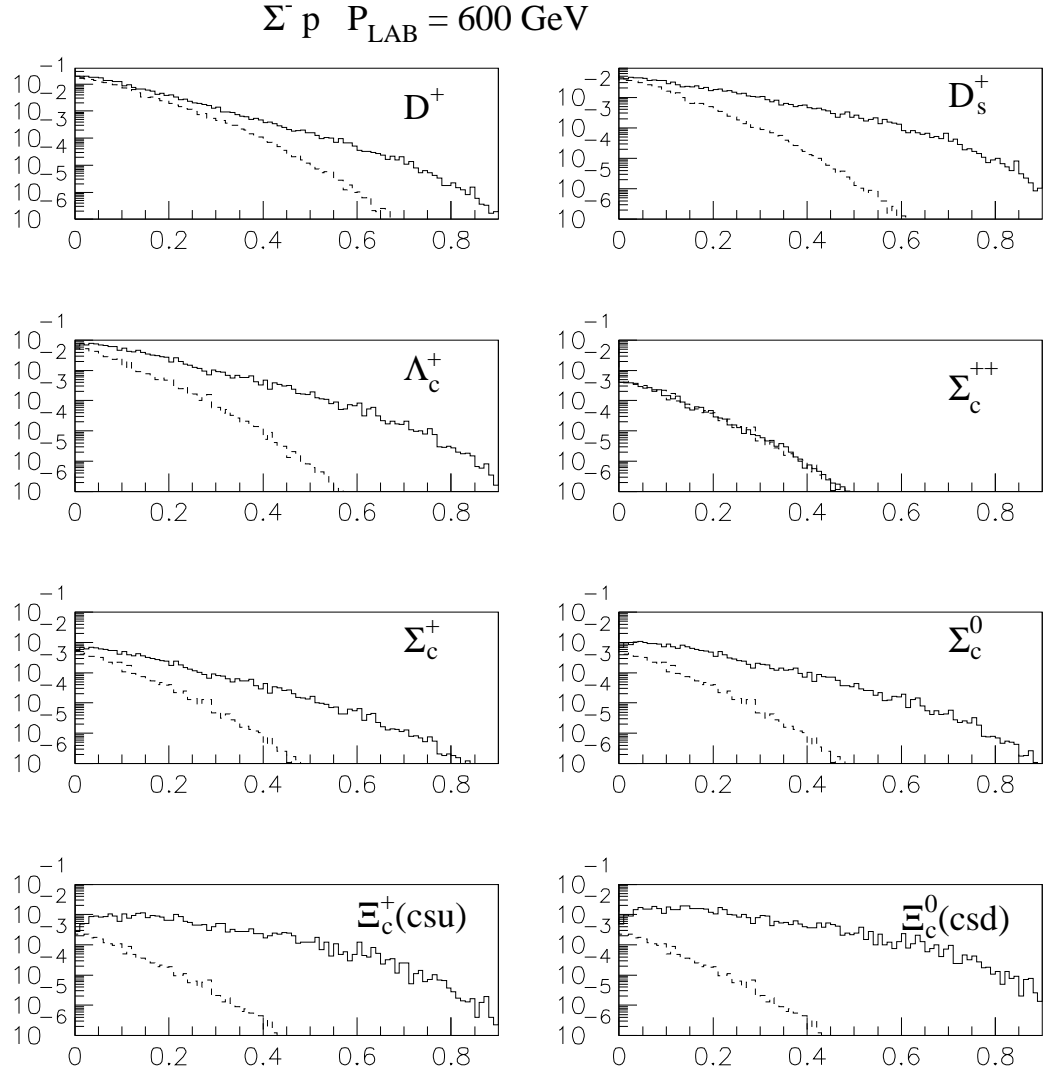


Figure 5: x -distributions of charmed mesons ($D^{*\pm}$ and $D_s^{*\pm}$) and baryons produced in $\Sigma^- p$ interactions at $P_{\text{LAB}} = 600 \text{ GeV}$. The solid (dashed) curves correspond to leading (non-leading) charmed hadron production.

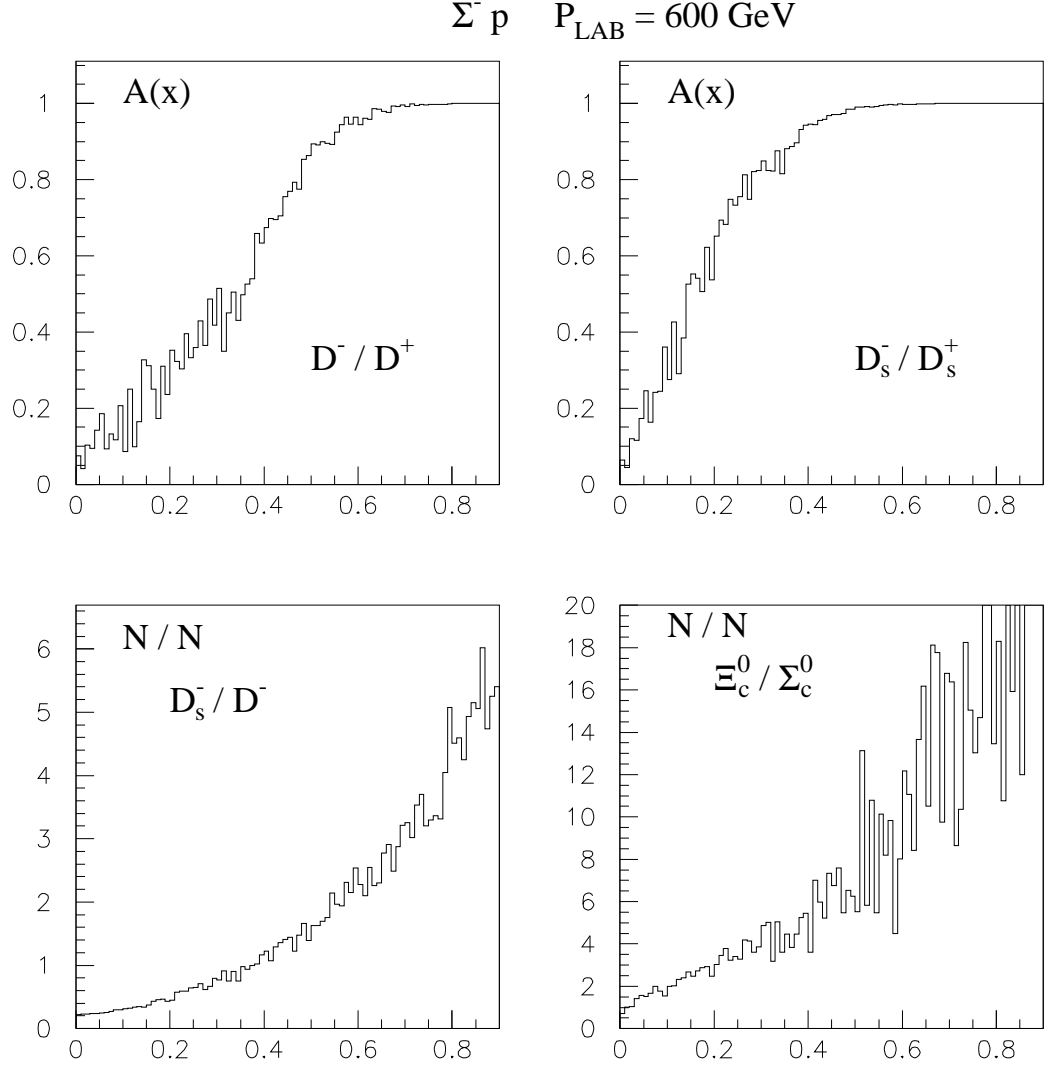


Figure 6: Production asymmetry $A(x)$ from (2) for $D^{*\pm}$ and $D_s^{*\pm}$ mesons (two upper histograms), produced in $\Sigma^- p$ interactions at $P_{\text{LAB}} = 600 \text{ GeV}$. Two lower plots present the ratio of the spectra of charmed hadrons with and without strange quarks (i.e. the D_s^{*-}/D^{*-} and $\Xi_c^0(cds)/\Sigma_c^0(cdd)$ ratios).